E. Magnetic Dating in Japan

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Geomagnetism not only varies in direction from place to place on the earth's surface but also undergoes a continued change of considerable magnitude over a time scale of decades or centuries. This continued change is called the secular variation.

This secular variation in the direction of geomagnetism has attracted attention of many geophysicists who have tried to trace this secular variation back into the past. Folgheraiter in Italy noticed about 70 years ago that ancient pottery could provide suitable materials to reveal the direction of geomagnetism in ancient times. His method is based on the fact that the pottery is magnetized in the direction coincident with that of the geomagnetism at the time when it was fired. This phenomenon is more or less figuratively explained as follows:

Generally speaking, natural clay or earth contains ferro or ferrimagnetic minerals such as magnetite, haematite and so on; these are assumed to be very small particles each of which has been magnetized in a certain direction. When raw clay is mixed together and shaped into a vessel, the direction of magnetism of each particle may take a random orientation so that the vessel as a whole does not manifest any magnetism in a definite direction. Then the vessel is fired. In this firing process, the magnetism of each particle becomes dynamic as temperature rises. In other words, due to the energy caused by heating, the magnetism of particles gets beyond the limit of standing still, and, so to speak, it begins to vibrate. When the temperature rises as high as 700° C., the magnetism of all mineral particles becomes dynamic. In this state the vessel is not magnetized at all as it was before. The magnetization does occur in the next cooling process.

In the cooling process when the temperature falls, the magnetism of particles gradually loses energy to vibrate and at last stands still. In this process, the magnetism of individual particles is influenced by the geomagnetism and is apt to stand still in the direction coincident with that of geomagnetism. The magnetism thus obtained is called the thermo-remanent magnetism which is generally so stable that it is thought to maintain its direction and intensity for a long time. Accordingly, if we measure the magnetism of ancient pottery vessels, it can reveal the direction of geomagnetism in those times. Such is the principle of Folgheraiter's method.

In practice, Folgheraiter selected Etruscan, ancient Greek and Roman pottery vases which were believed to have been fired in the upright position. Based on this assumption, he estimated the values of geomagnetic inclination in those times.

As is known, the direction of geomagnetism is generally indicated by two component angles, the geomagnetic declination and the geomagnetic inclination or dip. Inclination is the angle showing how much the geomagnetism dips downwards from the horizontal plane, and declination is the angle showing how much the direction of geomagnetism deviates horizontally to the east or west from

the geographic north. As far as the pottery is used as Folgheraiter did, the value of declination in the past cannot be revealed, because the pottery has been moved from its position at the time of firing.

In this respect lava flows, which are magnetized in a way similar to that of pottery, provide more suitable materials. They maintain the original position of their formation so that they yield the values not only for inclination but also for declination. For this reason, the interests of geophysicists have largely shifted from pottery to lava flows since the first decade of this century. The method has developed and flourished in the field of geophysics as a means of palæomagnetic studies.

It is rather strange that the method which originated from Folgheraiter's work on such an archæological material as pottery has been used exclusively for the purpose of geophysics, but has scarcely been applied to chronology in archæology. I suppose it is due to the fact that scarce attention has been given to the baked earth of ancient fireplaces or ceramic kilns which offer suitable materials comparable to lava flows.

In 1947, I was interested in Émil Thellier's work on bricks from churches to trace the secular variation in inclination at Paris. Then I perceived that the method could be effectively applied to the baked earth of prehistoric fireplaces. In the summer of that year, I collected the baked earth samples at Nishishiga shell-mound in central Japan and measured the direction of their magnetism. Since then baked earth samples were collected mainly from three sources: hearths, furnaces and ceramic kilns. A hearth is a simple fireplace made directly on the floor of a prehistoric dwelling pit; a furnace is a structure built up with sandy clay against the wall of a dwelling pit of the protohistoric and the historic ages; while a kiln is an ascending tunnel-like structure built with clay on the slope of a hill, in which ceramic ware was baked in historic times. These three sources yield the samples of various ages for the last 6,000 years in Japan.

The magnetism of baked earth is so weak that it is necessary to collect small blocks of baked earth at the site and measure their magnetism with a sensitive magnetometer in the laboratory. A small block of baked earth was sealed in a small cubic aluminium case so as to indicate the directions of the horizontal plane and the present geomagnetic north. Such samples, possibly more than six in number, were collected from well-baked and undisturbed portions of each fireplace.

The magnetometer used for measuring the magnetism of these samples is an astatic magnetometer. The principle of this magnetometer is rather simple. Two small magnets of nearly the same magnetic moment are connected by a rod so as to make the magnets take a reverse direction to each other with regard to their magnetism. The system of these connected magnets is suspended with a fine metal string. As the magnetic moments of the two magnets are balanced with one another, the system as a whole is more or less static in a magnetic field. The aim of measuring the weak magnetism of a baked earth sample is achieved by setting the sample near one of the magnets. As the magnets are strongly magnetized, the suspended system is easily deflected due to the magnetic force of the sample multiplied by that of the magnet.

The measurement was made around three main axes of each sample and the direction of magnetism was calculated. Then the mean direction of each set of

samples from the same fireplace was computed by Fisher's statistical method. For the samples from the sites far from Tokyo, the measurements were reduced to Tokyo.

Up to 1959, measurement was made on about 1,400 baked earth samples from 178 fireplaces and ceramic kilns. As a result, the direction of magnetism generally fell within the range from 40° to 60° for the inclination and from 20° E. to 30° W. for the declination. As these samples cover the period of the last 6,000 years or so, the result suggests that the direction of geomagnetism underwent secular variation within these ranges at least for the last 6,000 years in Japan.

In dating baked earth samples of unknown age, it is essential to establish a standard scale of secular variation in the direction of geomagnetism, to which the measurements on the samples in question should be compared. Unfortunately, there is no proved theory or law with which the magnitude of secular variation in the past could be computed. So, at present, the standard scale of secular variation is set up empirically.

For this purpose, it is necessary to obtain a number of data on the direction of geomagnetism of known age. Such data were obtained from the following sources. First, we have the records of regular magnetic surveys in Japan since 1883. Secondly, there are a number of records of declination observed by English and American navigators and some Japanese observers. The earliest of these records dates back to 1613 when a ship of the East India Company came to Japan. These old records were cited by Hisashi Shinozaki and Shuiti Imamiti. Thirdly, as to the period before these direct observation records are available, the measurements on the magnetism of lava flows of known dates meet the requirement. There are many old documents in which the descriptions of volcanic eruptions are found. Takesi Nagata, Yoshio Kato and other geophysicists have measured the magnetism of lava flows which were reasonably dated according to those descriptions in old documents. The lava flow of Mt. Fuji which was measured by Nagata dated to A.D. 864. Finally, I obtained the measurements on baked earth from ceramic kilns, the absolute dates of which are known, with almost certainty, from archæological evidence to be about A.D. 1300.

With these four kinds of measurements, the secular variation curves of geomagnetism were tentatively set up for the period of the last 1,700 years. It was achieved by the following procedure. Assuming that the secular variation is continuous and periodic in tendency, and that its changing rate and amplitude were smaller in inclination than in declination, the change of inclination was followed up first. For this purpose the values of inclination of known dates were projected on the co-ordinate taking the absolute time scale for the abscissa. Then several possible curves fitting the plotted points were assumed and examined one by one. In this process, I used for comparison the measurements on ceramic kilns only relative dates of which were known. As a result, a suitable secular variation curve of inclination was obtained for the period from A.D. 864 to the present.

Based on the curve of inclination just obtained, the values of declination were projected on a graph and the curve of declination was drawn so as to fit as well as possible the plotted points. Thus the curve of declination for the period from A.D. 864 to the present was obtained.

For the period before A.D. 864, I assumed that the geomagnetism underwent the secular variation similar to that estimated for the period after A.D. 864. And the curve of inclination was extrapolated as far back as 600 years. The curve of declination corresponding to this extrapolated inclination curve was obtained by using the measurements of fireplaces of these times.

The secular variation curves for about the last 1,700 years in Japan were thus obtained. Though these curves are tentative ones, the dates of archæological sites which are determined by these curves are in general consistent with archæological evidence. The work of checking these curves in more detail is in progress.

To set up the standard scale of secular variation for the period prior to these times, it is necessary to secure baked earth which can be dated by the radiocarbon method. At present only two such radiocarbon dates are available. One is that made by Libby on charcoal found on the floor of a prehistoric dwelling pit from which I collected baked earth samples. Thus the baked earth was dated as about 4,500 years ago. The other radiocarbon date was obtained by Crane at Michigan of a dug-out canoe from a peat formation. In this case there was no baked earth in the site. So I connected the radiocarbon date to the measurements on hearths of another site which contained the same type of pottery as that associated with the canoe. The radiocarbon date was 5,100 years B.P.

The secular variation curve for those times can be set up as more extensive measurements on baked earth coupled with radiocarbon dates become available. The magnetic dating principally depends on how accurately we can set up the standard scale of secular variation.

The present paper is an application of the method developed in the field of geogphysics to chronology. In Japan there are a number of geophysicists who are engaged in studies of palæomagnetism. For the present study I am greatly indebted to these geophysicists especially Professor Takesi Nagata and the staffs of Department of Geophysics of University of Tokyo.

The magnetic dating method is yet young and there are problems to be solved concerning its principle as well as its technics. As a means of dating the method seems to have become quite clear. In Japan, Kunio Kobayashi, Kanichi Momose and Haruo Domen measured the baked earth from prehistoric and protohistoric fireplaces. In England, Cook and Belshé made measurement on hearths and kilns of the Roman and the Medieval periods, and Aitken on Chinese Yüeh pottery.

In conclusion, to secure a sound basis of chronology for studies in anthropology and archæology, as many dating methods as possible should be used so that the results can be compared and checked with each other. For this purpose two requirements should be fulfilled. One is that the dating methods are independent of each other in their principles. The other is that the materials to which these dating methods are applied can be correlated as to their contemporaneity. At present, especially in Japan, three dating methods, namely the radiocarbon, the magnetic, and the archæological methods, may most adequately meet the requirements. The principles of these methods are quite different and the three kinds of materials, charcoal, baked earth and pottery are obtainable at the same time.

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